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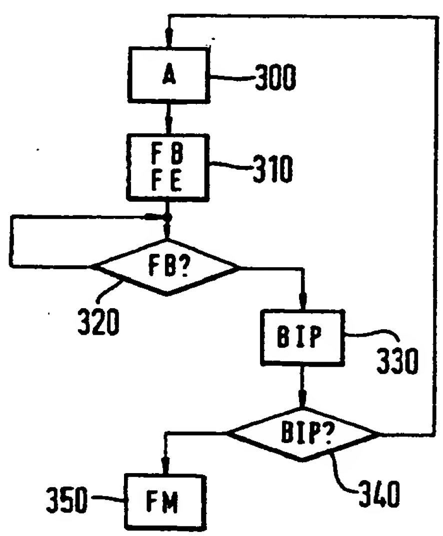
(54) **Recognising switching instants in the control of an electromagnetic switching device, eg in fuel injection systems**

(57) A method of controlling an electromagnetic switching device with an excitation winding and a movable armature comprises defining a time window by a first instant (FB) and a second instant (FE) in a step (310). Within the time window, the course of the current through and/or the voltage across the device is evaluated in a subsequent step (330) in order to recognise a switching instant (BIP) at which the armature reaches a new end position. In order to reduce the chance of interference signals being interpreted as switching instants, the time window is set small and enlarged only when no permissible switching instant was recognised within the time window. The system can be used in the control of an electromagnetic valve which controls the quantity of fuel to be injected into a diesel engine.

FIG. 3



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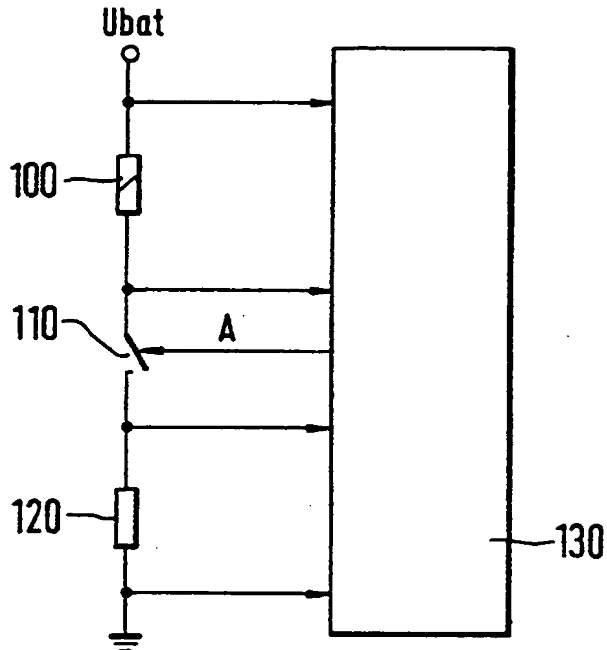

Ubat
100
110
A
120
130

FIG. 1

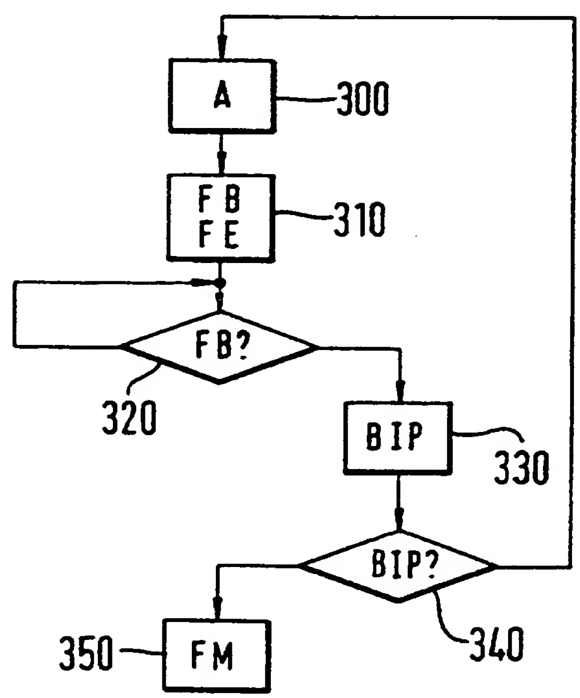

A
300
F B
F E
310
F B?
320
B IP
330
BIP?
340
350
F M

FIG. 3

FIG. 2

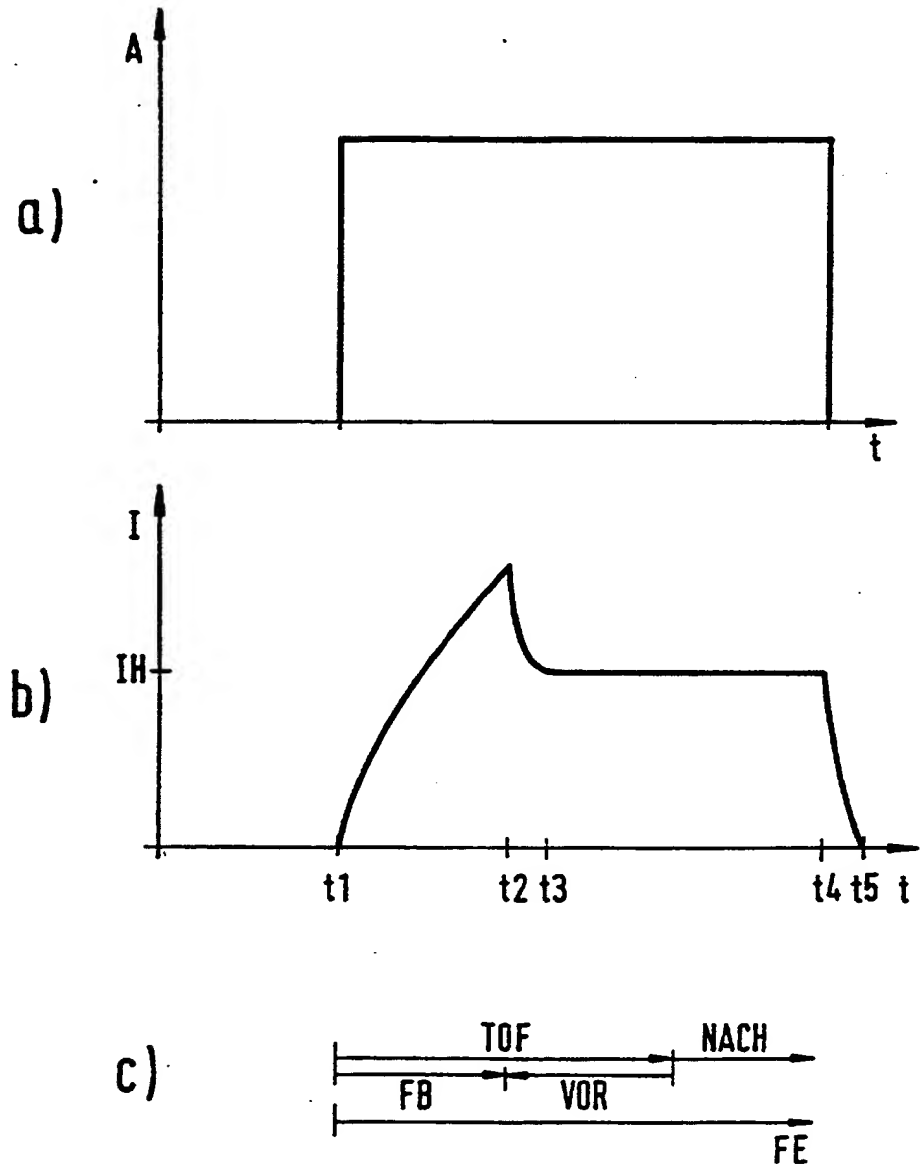


FIG. 4a

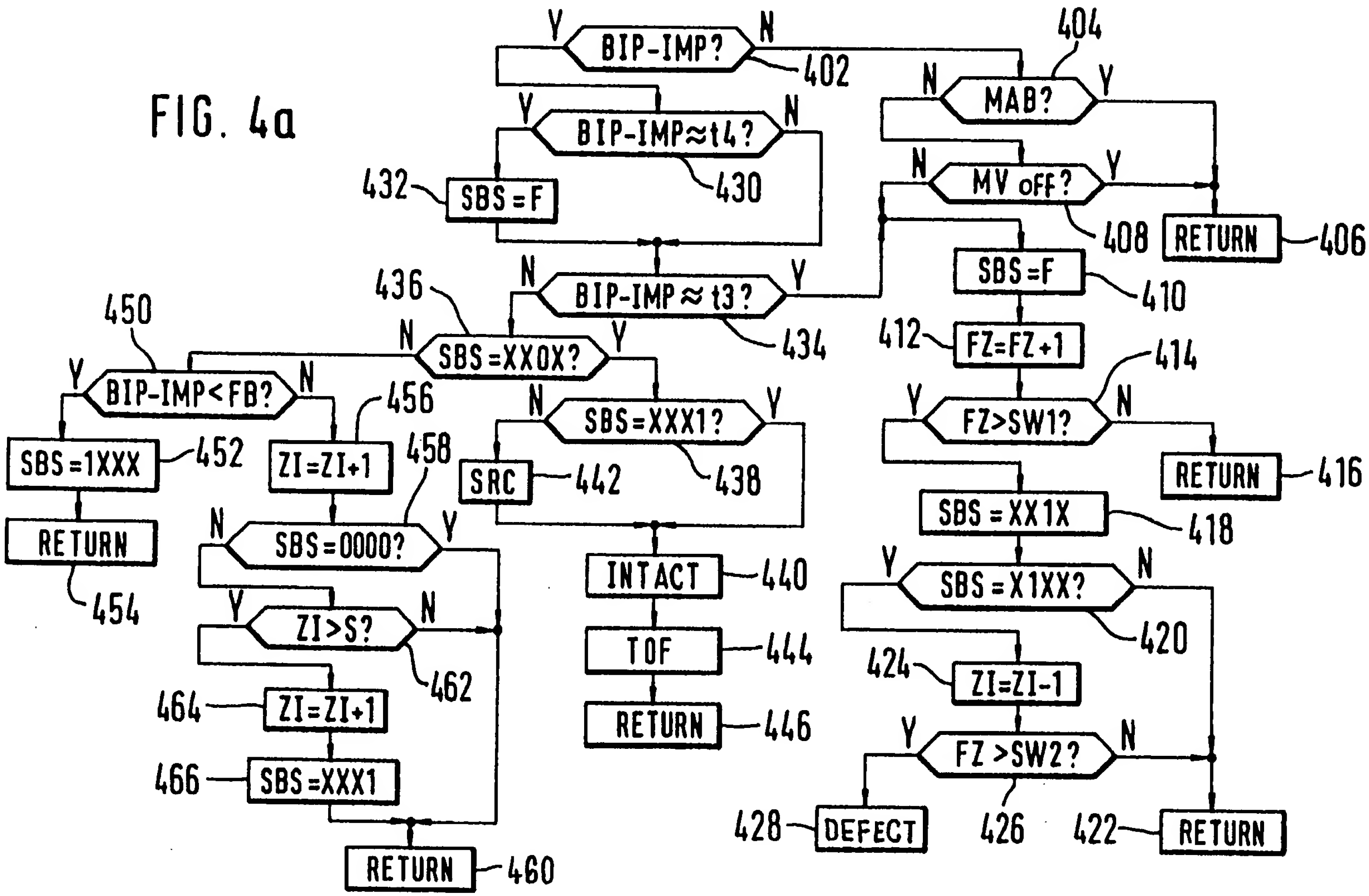
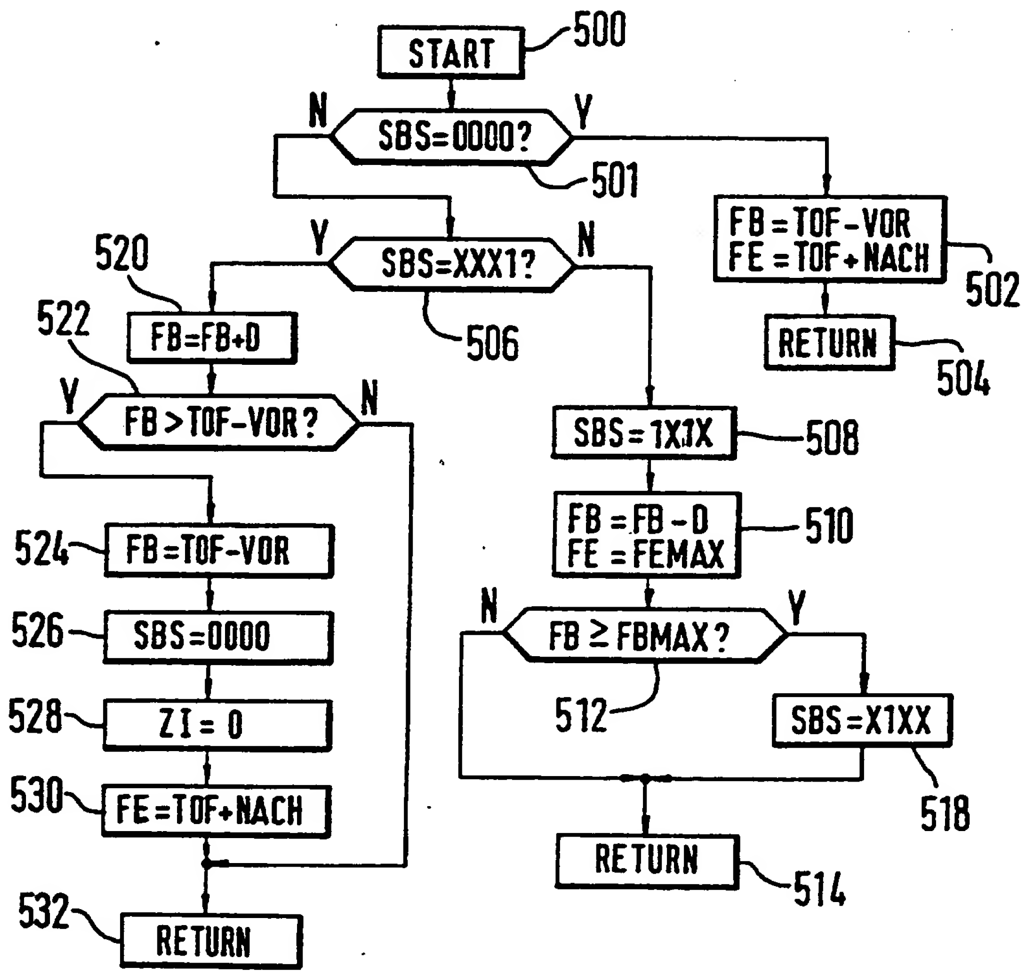

BIP-IMP?
402
MAB?
404
RETURN
406
MV off?
408
BIP-IMP≈t4?
430
SBS=F
432
SBS=F
410
FZ=FZ+1
412
FZ>SW1?
414
RETURN
416
SBS=XX1X
418
SBS=X1XX?
420
ZI=ZI-1
424
FZ>SW2?
426
DEFECT
428
RETURN
422
BIP-IMP≈t3?
434
SBS=XX0X?
436
SBS=XXX1?
438
SRC
442
INTACT
440
TOF
444
RETURN
446
BIP-IMP<FB?
450
SBS=1XXX
452
RETURN
454
ZI=ZI+1
456
SBS=0000?
458
ZI>S?
462
ZI=ZI+1
464
SBS=XXX1
466
RETURN
460

FIG. 4b


START
500
SBS=0000?
N
Y
501
FB = TOF-VOR
FE = TOF+NACH
502
RETURN
504
SBS=XXX1?
Y
N
506
520
FB=FB+D
522
FB > TOF-VOR?
Y
N
524
FB=TOF-VOR
526
SBS=0000
528
ZI = 0
530
FE=TOF+NACH
532
RETURN
SBS = 1X1X
508
FB = FB - D
FE = FEMAX
510
FB ≥ FBMAX?
N
Y
512
SBS = X1XX
518
RETURN
514

METHOD OF AND CONTROL MEANS FOR CONTROLLING AN ELECTROMAGNETIC SWITCHING DEVICE

The present invention relates to a method of and control means for controlling an electromagnetic switching device.

A method and a device for the control of an electromagnetic switching element are described in DE-OS 34 26 799 (US 4 653 447), in particular for the control of an electromagnetic valve which controls the quantity of fuel to be injected into a Diesel engine. The valve comprises an excitation winding and a movable armature. For the movement of the armature, a current and/or a voltage is applied to the excitation winding. Within a time window which is defined by a first value and a second value, the course of the current and/or the voltage is evaluated in order to detect the instant at which the armature reaches its new end position.

The instant at which the armature reaches its new end position has a substantial influence on the accuracy of the admetering of the fuel. For this reason, this instant must be recognised reliably and differentiated from interference signals. In the case of too large a time window, interference signals can be interpreted as switching instants. In the case of too small a time window, the switching instant does not lie within the time window in all operational states of the engine.

There is therefore a need for reliable recognition of the instant at which the armature reaches its new end position in a method and control means for the control of an electromagnetic switching device.

According to a first aspect of the present invention there is provided a method of controlling an electromagnet switching device with

an excitation winding and a movable armature, wherein a first or start instant and a second or end instant define a time window and wherein the course of the current and/or the voltage are evaluated within the time window in order to recognise a switching instant at which the armature has reached a new end position, characterised in that the time window is enlarged when no permissible switching instant is recognised within the time window.

Preferably, the first instant is increased gradually until reaching a maximum value, when no permissible switching instant was recognised within the window. Preferably, the second instant is increased immediately until reaching a maximum value, when no permissible switching instant was recognised within the window. For preference the first instant is gradually reduced to a normal value when a permissible switching instant was recognised within the enlarged time window, whilst the second instant can be set to its normal value on reaching the normal value for the first instant.

Expediently, both the first instant and the second instant are preset starting out from a stored switching instant and a respective anticipatory control value. The stored switching instant can be determined starting out from a filtered permissible switching instant.

Preferably, a permissible switching instant is recognised when all conditions of the monitoring function are fulfilled.

According to a second aspect of the invention there is provided control means for controlling an electromagnet switching device with an excitation winding and a movable armature, wherein a first instant and a second instant define a time window and the control means comprises means which evaluate the course of the current and/or the voltage within the

time window in order to recognise a switching instant at which the armature has reached a new end position and means which enlarge the window when no permissible switching instant is recognised within the window.

A method exemplifying and control means embodying the invention may have the advantage that the instant at which the armature reaches its new end position can be recognised reliably.

An example of the method and embodiment of the control means of the present invention will now be more particularly described with reference to the accompanying drawings, in which:

Fig. 1 is a schematic diagram of control means in which a method exemplifying the invention can be performed;

Fig. 2 is a set of diagrams illustrating signals and parameters connected with the method;

Fig. 3 is a flow diagram of basis steps in the method;

Fig. 4a is a flow diagram of steps in one part of the method; and

Fig. 4b is a flow diagram of steps in another part of the method.

Referring now to the drawings, in the following a method exemplifying and control means embodying the invention are described by reference to an electromagnetic valve serving for control of the quantity of fuel to be injected into an internal combustion engine. In modern fuel-admetering systems, in particular for Diesel engines, electromagnetic valves are used to control the admetering of the fuel. In that case, the instant at which the valve closes or opens respectively determines the beginning or end of the fuel admetering. In order to make an exact admetering of fuel possible, the closing instant and/or the opening instant of the valve must be recognised reliably.

For the control of the admetering of fuel, the valve is acted on by current or voltage.

A simplified illustration of a circuit arrangement incorporating such an electromagnetic valve is illustrated in Fig. 1. Only the most essential elements are illustrated in Fig. 1. A coil of an electromagnetic valve is denoted by 100, a switching means by 110 and a current-measuring resistor by 120. The coil 100, the switching means 110 and the resistor 120 are connected in series between a supply voltage source Ubat and ground. In the Fig. 1 circuit, the load is connected to battery voltage and the switching means 110 is arranged between the coil 100 and the resistor 120.

The method and the control means are not restricted to this arrangement, but can be used with other arrangements. For example, it is feasible to provide a second switching means which connects the coil 100 with battery voltage. Moreover, it is possible to arrange the current-measuring means between the switching means 110 and the coil 100 or between the coil 100 and the supply voltage source.

The circuit also includes a control unit 130, which is connected with the terminals of the coil 100 and with the terminals of the resistor 120. The control unit 130 acts on the switching means 110 by way of a drive control signal A. The unit 130 computes the signal A starting from different detected operational characteristic magnitudes of the engine. In dependence on the signal A, a current flows through the coil 100 with the consequence that the valve assumes different settings and an injection takes place.

In Fig. 2a the drive control signal A, and in Fig. 2b the current I which flows through the coil, are entered as a function of the time t.

At the instant t1, the drive control signal A changes from its low level to its high level. This has the consequence that the switching means 110 enables the current flow. The current I rises from this instant according to a preset function over time. At the instant t2, the free current rise is interrupted and there is change to a current regulation. From this instant onwards, the current I is regulated to a holding current IH, which is reached at the instant t3. The current regulation preferably takes place by keying of the switching means 110. At the instant t4, the drive control signal A is reduced, which has the consequence that the current falls and reaches zero at the instant t5.

The instant t1 is chosen so that the current reaches the holding current IH before the valve reaches its new switching state. From the instant t1 on, the instant at which the magnetic valve reaches its new end position is ascertained by evaluating the voltage across the magnetic valve. For this purpose, a time window, within which the switching instant can be expected to lie, is defined.

In Fig. 2c the instants FB and FE at which the measurement window respectively starts and ends, are shown by arrows starting from the instant t1. The instant at which the last switching instant was recognised is indicated by an arrow TOF. Starting from the instant TOF, the start FB of the measurement window is determined by subtraction of a time span VOR and the end FE of the window is determined by addition of a time span NACH. The instant FB corresponds with the instant t1.

At the time of the beginning of the measurement window FB, the current is regulated down to the holding current and a procedure for the recognition of the switching point through evaluation of the temporal course of the voltage across the coil 100 is initiated at the same time.

This evaluation ends with the end FE of the measurement window.

If no switching instant is recognised in this measurement window, which is defined by the instants FB and FE, corresponding measures must be initiated. An absence of the switching instant can be due to the measurement window having been chosen too small or being in the wrong time range. It is also possible that no valve drive control took place at all or that a fault has arisen.

The measurement window, in particular the beginning FB of the window, cannot be chosen to be as large as desired, since the beginning FB of the window fixes the instant at which the current is regulated down to the holding current. If this current is chosen to be too early, the valve does not switch sufficiently rapidly or even not at all.

If either the instant t1 or the instant t4 lies within the window, it is recognised as switching instant.

A flow diagram for clarification of the manner of procedure is shown in Fig. 3. The drive control signal A is issued in a first step 300. The beginning FB and the end FE of the measurement window are preset in a subsequent step 310.

The beginning FB results from the time TOF of the last detected switching instant less a first anticipatory control value VOR, the determination of the value FB being shown in more detail in Fig. 4a. If no switching instant has yet been detected in the preceding valve drive cycles, a control value is drawn on as substitute value for computation purposes. The window end FE is computed from the time TOF of the last detected switching instant plus a second anticipatory control value NACH. As for the computation of the beginning of the window, a substitute value is used for the time TOF when such a time has not yet been detected.

A subsequent interrogation step 320 checks whether the beginning FB of the window is reached. If this is not the case, the interrogation step 320 is repeated. If the beginning FB of the window is reached, the switching instant, which is also denoted as BIP, is detected in a step 330. For this, the current is regulated in the illustrated example to a preset value, in particular a holding current IH. The evaluation of the switching instant in the step 330 takes place at the instant of the window end FE.

The holding current IH is dimensioned so that it is sufficient to keep the valve in its instantaneous setting. This current is usually less than the current required to bring the valve into that setting.

For the detection of the switching instant BIP, the voltage across the valve is evaluated in the illustrated example. As soon as the temporal course of the voltage exhibits a discontinuity, a signal is presented, which is denoted as BIP-IMP. Evaluation takes place in an output stage of the control unit 130.

An interrogation step 340 checks whether the BIP-IMP signal was permissible. If this is not the case, a fault FM is recognised in a step 350. Otherwise, the sequence is repeated in the step 300 during the next admetering phase. The interrogation step 340 is illustrated in greater detail in Fig. 4b.

If, at the window end FE, a switching instant was recognised within the window defined by the values FB and FE, this is then checked in respect of plausibility. For diagnosis and further evaluation, the result of the check is filed in a storage device.

For the checking of the plausibility of the switching instant BIP-IMP, the procedure is as illustrated in Fig. 4a. The flow diagram in

Fig. 4a represents only one possible example. Thus, steps can be omitted, added or performed in a different sequence. The values of a status storage device can also be varied.

A first interrogation step 402 checks whether a switching instant BIP-IMP has occurred in the measurement window. If this is not the case, an interrogation step 404 checks whether a MAB signal is present, which signal indicates that an external valve switching-off signal is present. This switching-off signal indicates that the valve is not driven. In the presence of the signal MAB, no switching instant can be ascertained, since the valve was not conducting current.

If this is the case, a main program is returned to in a step 406. In the case of a return in the step 406, the return takes place without a switching instant having been recognised.

If the MAB signal is not active, an interrogation step 408 follows, which checks whether the magnetic valve MV is switched off. If this is the case, the main program is returned to in the step 406. If the interrogation step 408 recognised that the valve was not switched off, then no switching instant was recognised, although one would have had to be recognised in view of the operating conditions.

Therefore, a status storage device SBS is set in a step 410 to a value F which indicates that no switching instant has occurred in the measurement window. Subsequently, the count value FZ of a fault counter is increased by 1 in a step 412.

A subsequent interrogation step 414 checks whether the count value FZ is greater than a first threshold value SW1. If this is not the case, the main program according to Fig. 3 is returned to in a step 416. If the count value FZ is greater than the threshold value SW1, the status

storage device SBS is set to a corresponding value XX1X in a step 418. This value indicates that a BIP search is to be started. For this purpose, the third place of the storage device is set to 1. A subsequent interrogation step 420 checks whether the second place of the status storage device SBS is set to 1, thus X1XX. If this is not the case, the program returns to the main program in a step 422.

If the interrogation step 420 recognises that the status storage device SBS is set to 1 at its second place, then this indicates that the window has its maximum size. In that case, the count value ZI is reduced by 1 in step 424. The subsequent interrogation 426 checks whether the fault count value ZI is greater than a second threshold value SW2. If this is so, the program ends in a step 428 and recognises a defect. In this case, a defect is present in the admetering system, since no switching instant BIP-IMP was recognised even though the window was of maximum size.

Otherwise, the program jumps returns to the main program in the step 422. During the return jump in the step 416, the return takes place subject to the condition that no BIP-IMP was found, although one should have been present. If no switching instant is found several times, the BIP search is activated in the step 418. When the window reaches a certain size without finding a switching instant, the method recognises a defect. On the return jump in the step 422, the status storage device is set so that the BIP search continues to be active.

If the interrogation step 402 recognises that a switching instant was present, an interrogation step 430 checks whether the switching time lies in the region of the magnitude of the switching-off time t4. If this is the case, the status storage device SBS is set to the value F

which indicates that no switching instant was recognised.

If the interrogation step 430 recognised that the switching instant BIP-IMP was present in the region of the switching-off instant t4 of the valve, an interrogation step 434 is performed, as it is also after the step 432. This interrogation step 434 checks whether the switching instant BIP-IMP lies in the region of the switching-over time t3 at which the holding current is initiated. If this is the case, the step 410 follows, in which the status storage device SBS is set to the value F. If this is not the case, i.e. the recognised switching instant BIP-IMP lies between the times t3 and t4, an interrogation step 436 follows.

The interrogation step 436 checks whether the status storage device SBS is set to a value XX0X which indicates that the window search is inactive or concluded. This means that the interrogation step 436 checks whether the third place of the status storage device SBS is occuped by the value zero. If this is the case, i.e. the window search is either inactive or concluded, an interrogation step 438 takes place. The interrogation step 438 checks whether the status storage device SBS is occupied in such a manner, in particular by XXX1, that it indicates that the window is to be made smaller. If this is so, a step 440 follows immediately.

If this is not the case, i.e. the window search is not active and the window is not reduced, then a signal "range check" SRC follows in a step 442. This means that it is checked whether the value of the switching instant departs from an expected value by no more than a difference value. As an expected value, for example, the value TOF can be used. The difference value is preferably preset in dependence on the supply voltage.

If the found value does not differ from the expected value, the step 440 takes place in that a switching instant was recognised as intact. If the step 440 is reached, a permissible switching instant was recognised. Subsequent to the step 440, the instant TOF is determined again in a step 444 by filtering. The filtering is carried out in such a manner that a sliding mean value is formed over a certain number of plausible measurement values. Subsequently, the main program is returned to in a step 446. This return jump takes place, in particular, when the switching instant was recognised, free of fault, without BIP search.

If the interrogation step 436 recognised that the BIP search was active, i.e. that the status storage device SBS was set to the value XX0X, then an interrogation step 450 takes place. The interrogation step 450 checks whether BIP-IMP has occurred earlier than expected, in particular before the window beginning FB. If this is the case, the status storage device SBS is set in such a manner to 1XXX in a step 452 that the search window is enlarged. This takes place, for example, by the first place of the status storage device being set to 1.

Subsequently, a return to the normal main program takes place in a step 454. During this return jump, the status storage device is set in such a manner that the window search is active and the window is to be enlarged.

If the interrogation step 450 recognised that the switching instant BIP-IMP was not earlier than expected, then a step 456 follows, in which the counter count value ZI is increased by 1. In this case, the switching instant is found and lies within the measurement window which is defined by the values FB and FE. The number of the found switching instants is counted in the counter. A subsequent interrogation step 458 checks

whether the BIP search is still active. If this is not the case, a return to the main program follows in a step 460.

If the interrogation step 458 recognises that the BIP search is active, an interrogation step 462 checks whether the counter count value ZI is greater than a threshold value S. If this is not the case, a return to the main program follows in the step 460. If the count value ZI is not yet greater than the threshold value S, it is increased by 1 in a step 464. Subsequently, the status storage device SBS is set in such a manner, in particular to the value XXX1, in a step 466 that the window is made smaller. Subsequently, a return to the main program takes place in the step 460.

The course of the step 340 for adaptation of the window size is illustrated in Fig. 4b. After the start of the sequence in a step 500, an interrogation 501 follows. This checks whether the status storage device SBS assumes the value zero. If this is the case, i.e. the window search is not active, i.e. the BIP window is found and has its smallest size, a step 502 follows, in which the beginning FB of the window starting from the time TOF and the anticipatory control value VOR is determined as FB = TOF-VOR. Correspondingly, the window end FE is preset starting out from the time TOF plus the time NACH. This means that the two values FE and FB, which define the window, are set to their normal values. Subsequently, a return to the main program takes place in a step 504.

If the interrogation step 501 recognises that the status storage device SBS is not equal to zero, then an interrogation step 506 follows, which checks whether the fourth place of the status storage device SBS assumes the value 1, thus the value XXX1. This indicates that the window

is to be made smaller. If this is not the case, then a step 508 follows, in which the status storage device SBS is set so that it indicates that the BIP search is active and the window is to be enlarged. This takes place by the first and the third place of the status storage device SBS being set to 1, thus to 1X1X.

In a step 510, the beginning of the window FB is reduced by a value D, thus the window is enlarged, and the window end FE is set to its maximum value FEMAX. An interrogation step 512 then checks whether the window, in particular the beginning FB of the window, has reached its maximum value FBMAX. If this is not the case, a return to the main program follows in a step 514. If the maximum size is reached, the status storage device SBS is set in step 518 to a value X1XX which indicates that the maximum window size is reached, thus a value in which the second place is occupied by 1. Subsequently, a return to the main program takes place in the step 514.

It is achieved by this procedure, in particular in the steps 510 and 512, that the beginning or first instant FB is gradually increased until reaching a maximum value FBMAX and that the end or second instant FE is increased immediately to a maximum value FEMAX when no permissible switching instant was recognised within the time window.

If the interrogation step 506 recognised that the status storage device SBS is set in such a manner that the window is to be made smaller, then this reduction takes place in a step 520 in that a presettable value D is added to the window beginning time FB. A subsequent interrogation step 522 checks whether the window beginning time FB is greater than the time TOF minus VOR, i.e. it is checked whether the window beginning FB has been moved sufficiently closely to the switching instant. If this is

not the case, a return to the main program takes place in a step 532.

If this is the case, i.e. the window has reached its normal value TOF-VOR, then the window beginning FB is set in a step 524 to the normal value TOF-VOR. Subsequently, the status storage device SBS is set to zero in a step 526. In a step 528, the counter count value ZI is set back to zero. Subsequently, the window end FE is set to the value TOF+NACH in a step 530. Subsequently, a return to the main program takes place in a step 332. For this return jump, the window has its normal size and the search is no longer active.

It is achieved by this manner of procedure, in particular by the steps 520 to 530, that, on the recognition of a permissible switching instant, the first instant FB is gradually reduced until reaching a normal value and that, on reaching the normal value for the first instant, the second instant FE is set to its normal value.

CLAIMS

1. A method of controlling an electromagnetic switching device with a movable armature, the method comprising the steps of evaluating the course of at least one of the voltage and the current through the device during a time window defined by a start instant and an end instant so as to recognise a switching instant at which the armature has reached a new end position and enlarging the time window if no permissible switching instant is recognised within the window.

2. A method as claimed in claim 1, wherein the step of enlarging the window comprises gradually increasing the start instant until reaching a respective predetermined maximum value.

3. A method as claimed in claim 1 or claim 2, wherein the step of enlarging the window comprises immediately increasing the end instant until reaching a respective predetermined maximum value.

4. A method as claimed in any one of the preceding claims, comprising the step of gradually reducing the start instant to a respective predetermined normal value when a permissible switching instant is recognised within the time window.

5. A method as claimed in claim 4, comprising the step of setting the end instant to a respective predetermined normal value when the start instant has reached said normal value thereof.

6. A method as claimed in any one of the preceding claims, wherein the start instant is preset in dependence on a stored switching instant and a respective anticipatory control value.

7. A method as claimed in any one of the preceding claims, wherein the end instant is preset in dependence on a stored switching instant and a respective anticipatory control value.

8. A method as claimed in claim 6 or claim 7, wherein the stored switching instant is determined in dependence on a filtered permissible switching instant.

9. A method as claimed in any one of the preceding claims, wherein a permissible switching instant is recognised when all of a plurality of monitoring conditions are fulfilled.

10. A method as claimed in claim 1 and substantially as hereinbefore described with reference to the accompanying drawings.

11. Control means for controlling an electromagnetic device with a movable armature, the control means being arranged to evaluate the course of at least one of the voltage and the current through the device during a time window defined by a start instant and an end instant so as to recognise a switching instant at which the armature has reached a new end position and to enlarge the time window if no permissible switching instant is recognised within the window.

12. Control means substantially as hereinbefore described with reference to the accompanying drawings.

The Patent Office

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Claims searched: 1 to 12

Examiner: John Twin
Date of search: 11 June 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): F1B (BBG, BBH); G1N (NADP, NAHF, NCXA)

Int Cl (Ed.6): F02D 35/00, 41/30, 41/40; F02M 51/06

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	EP 376897 A1	(Marelli) - see eg column 1, lines 30-41; column 3, lines 15-29	1
Y	US 4653447	(Robert Bosch)	1

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.